UNITED STATES DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

De Beque Area

OIL AND GAS INVESTIGATIONS
MAP OM 114 (IN 2 SHEETS) SHEET 2

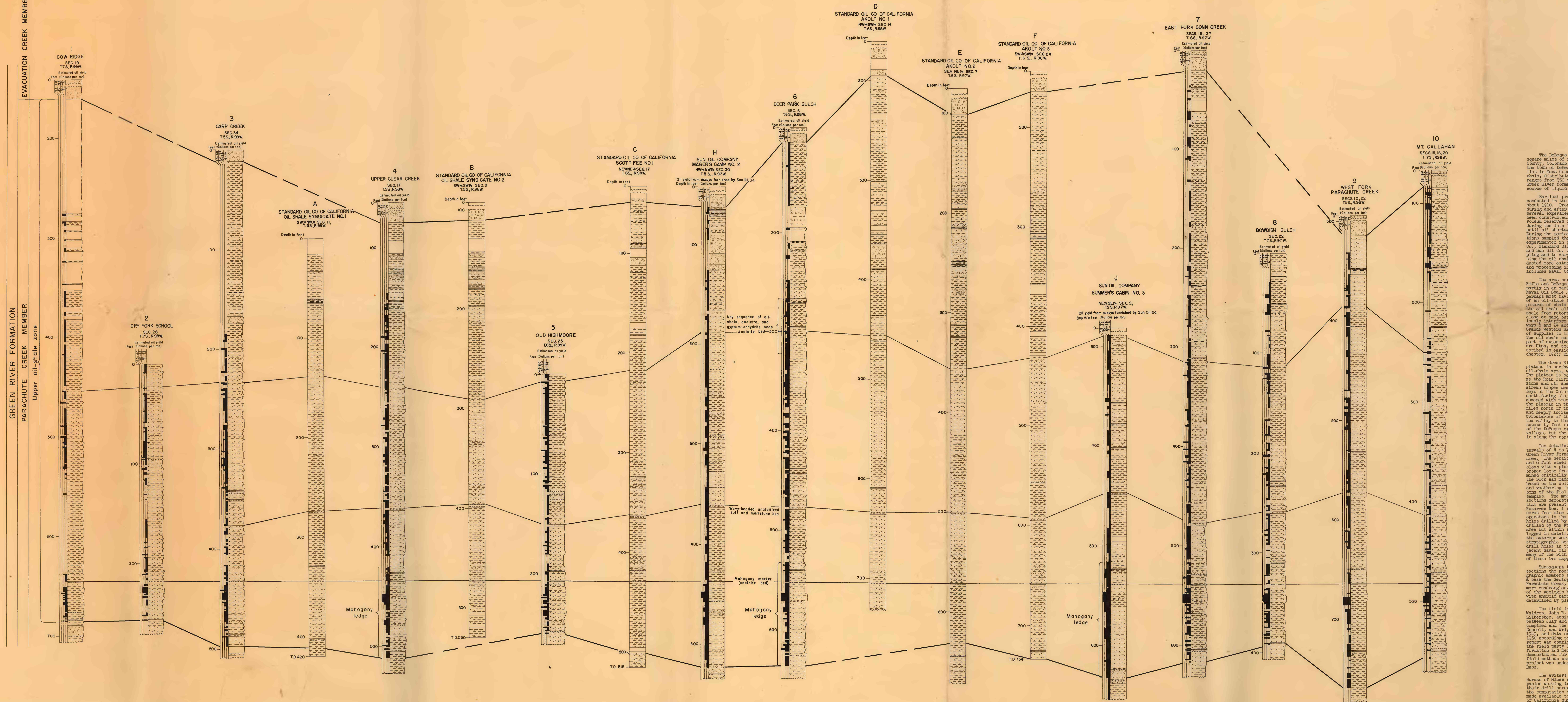
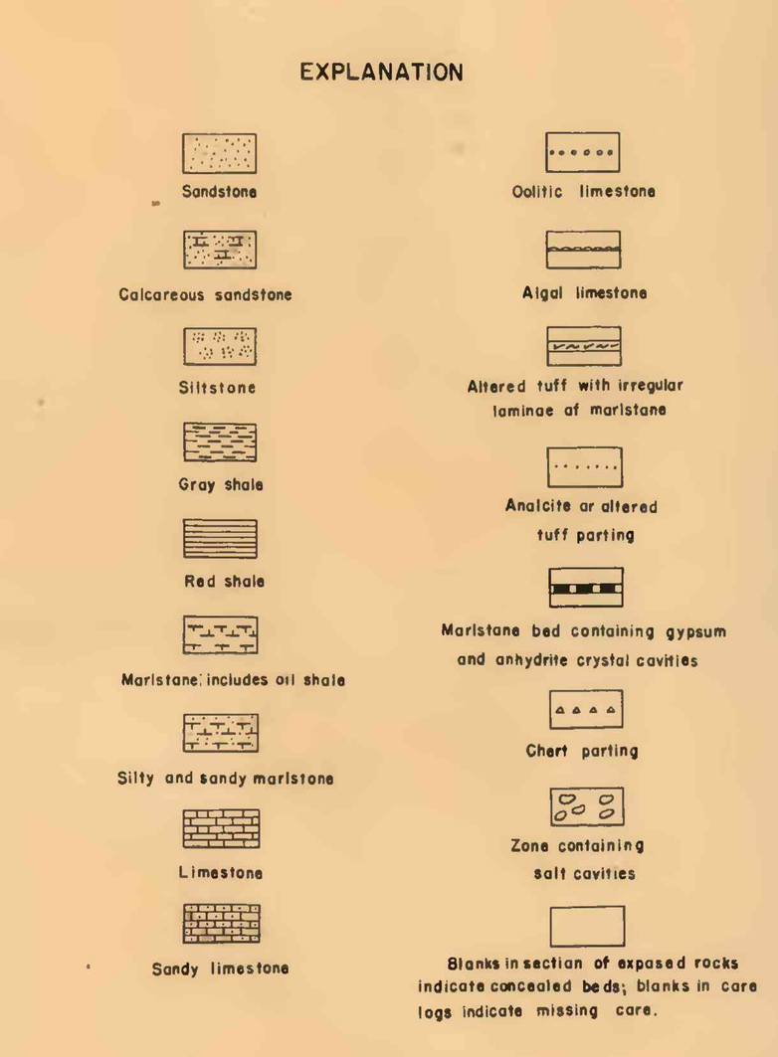


FIGURE 4. DETAILED COLUMNAR SECTIONS OF THE UPPER OIL-SHALE ZONE SHOWING CORRELATION OF SEVERAL KEY BEDS AND THEIR ESTIMATED OIL YIELDS



Columnar sections measured, and cores logged by F. R. Waldron J. R. Donnell, J. C. Wright, and W. M. Zilbersher, assisted by W. A. Jenkins, Jr.

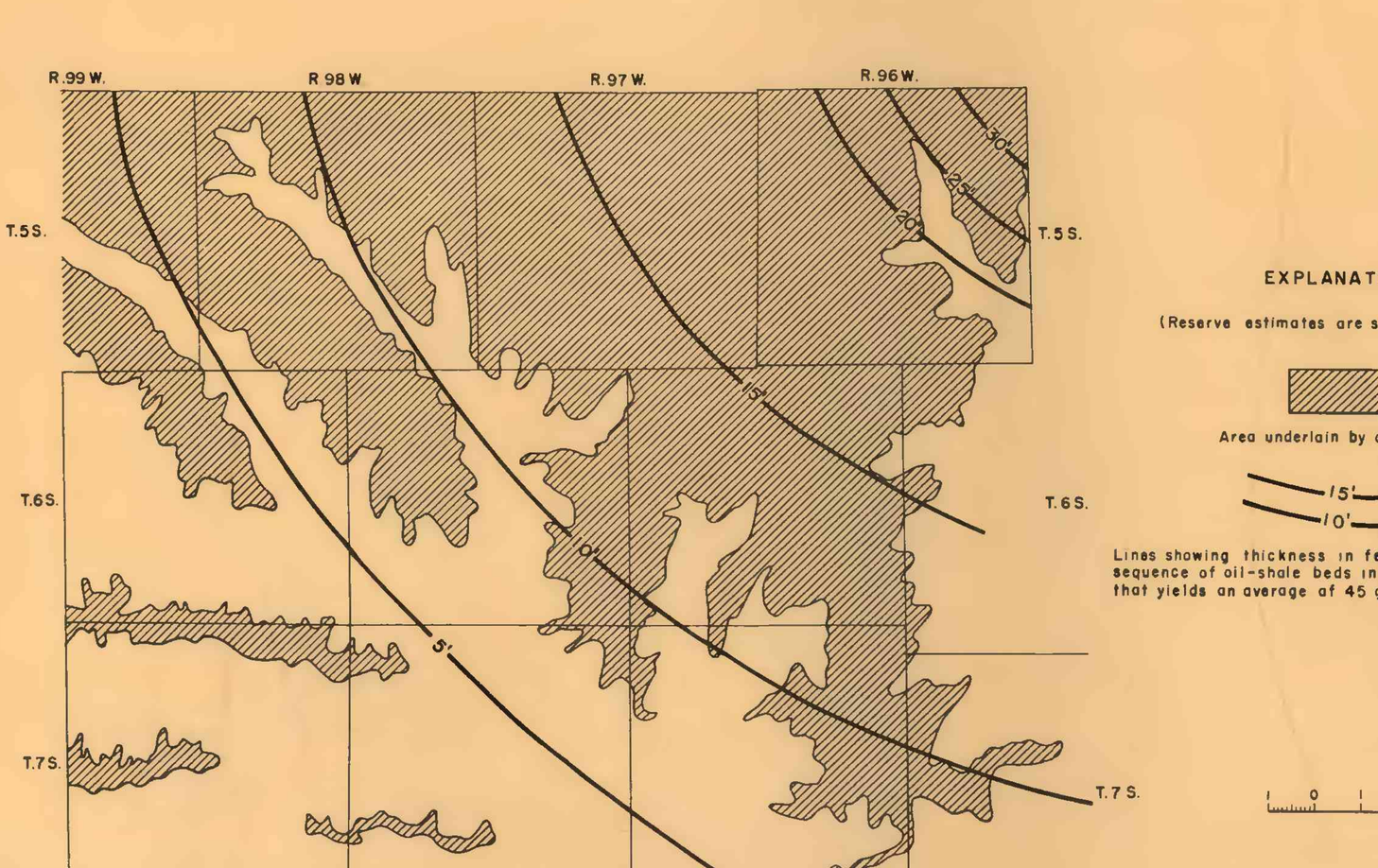


FIGURE 5. MAP SHOWING DISTRIBUTION AND THICKNESS OF PART OF THE MAHOGANY LEDGE THAT YIELDS AN AVERAGE OF 45 GALLONS OF OIL PER TON

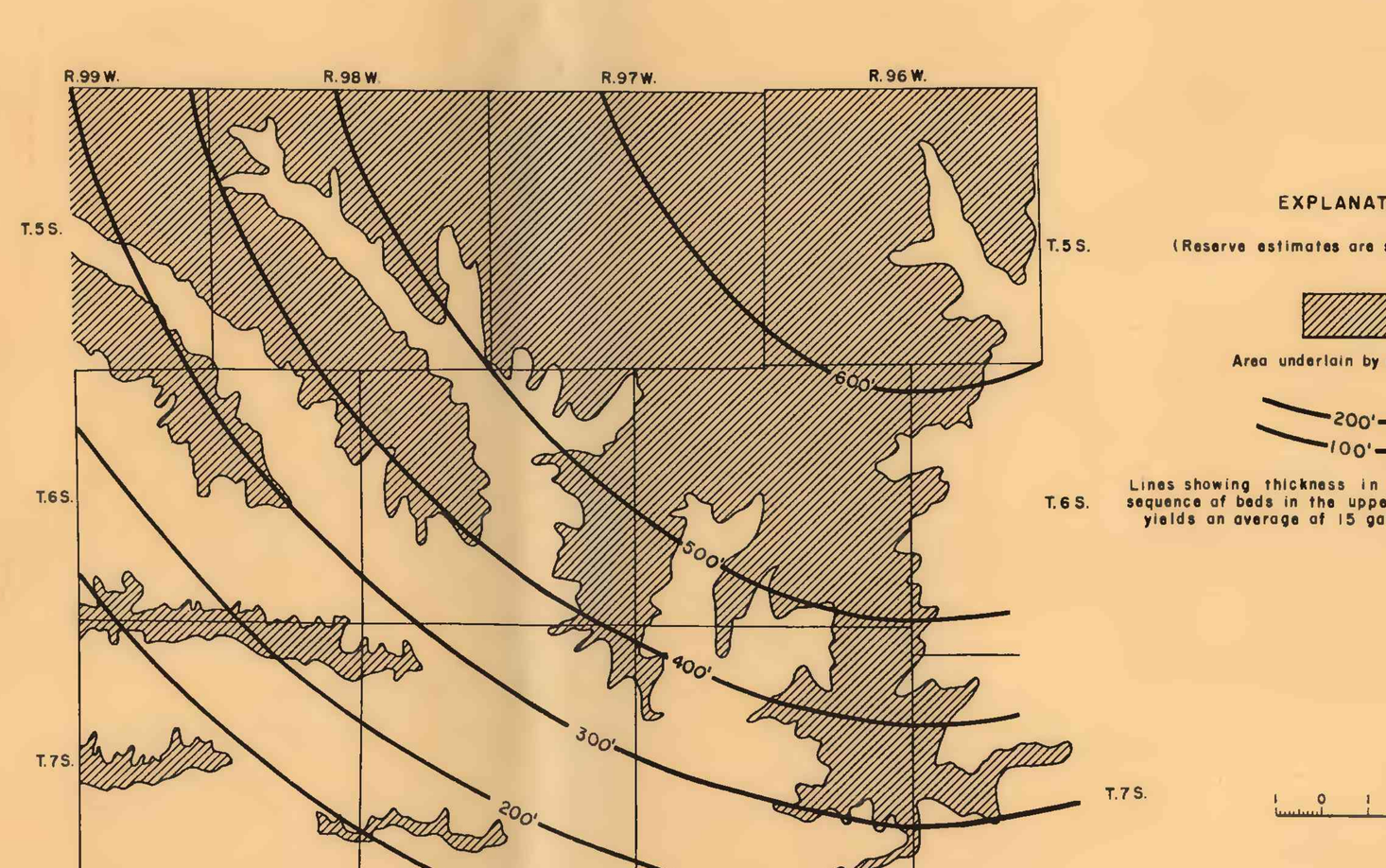


FIGURE 8. MAP SHOWING DISTRIBUTION AND THICKNESS OF PART OF THE UPPER OIL-SHALE ZONE THAT YIELDS AN AVERAGE OF 15 GALLONS OF OIL PER TON

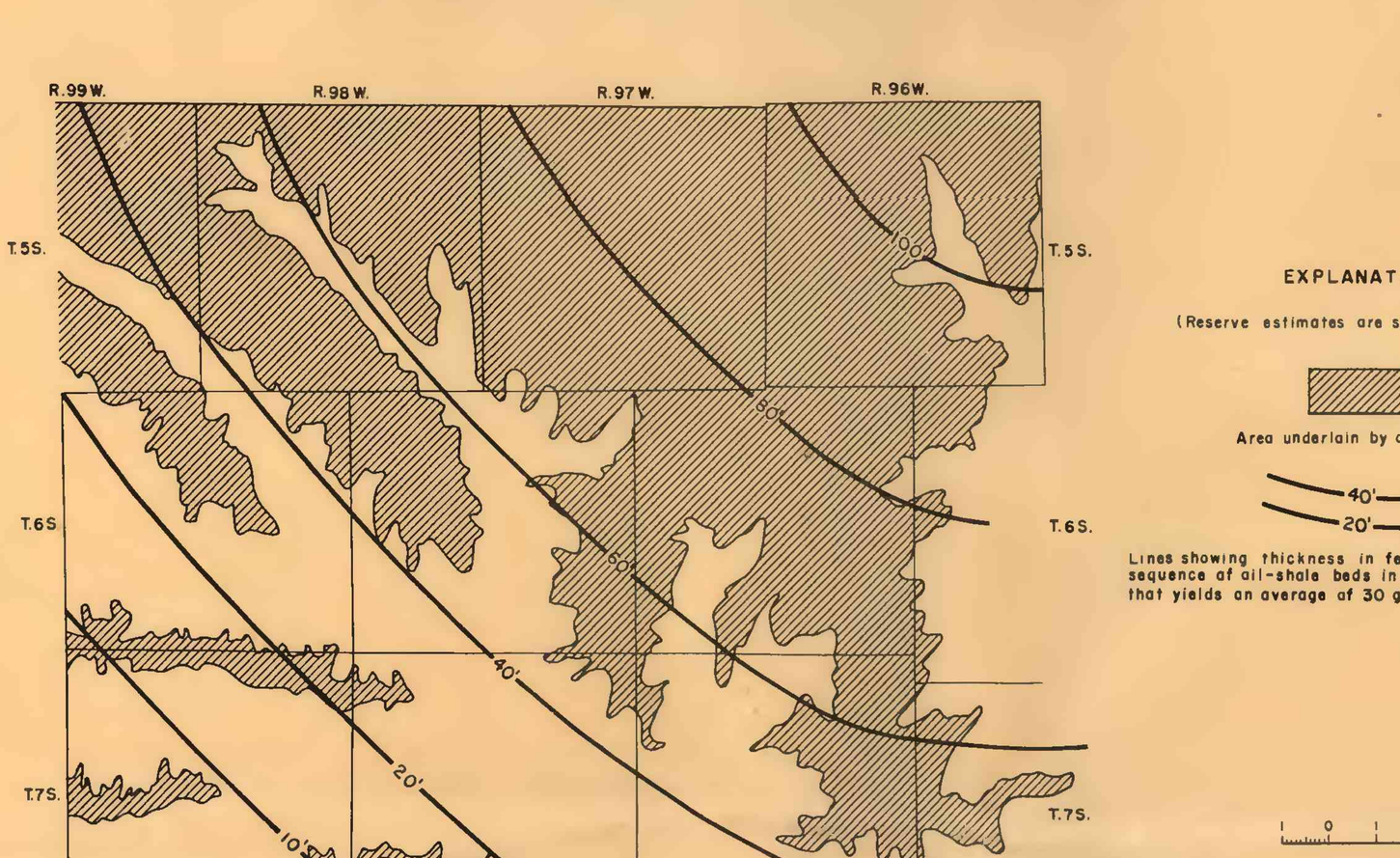


FIGURE 6. MAP SHOWING DISTRIBUTION AND THICKNESS OF PART OF THE MAHOGANY LEDGE THAT YIELDS AN AVERAGE OF 30 GALLONS OF OIL PER TON

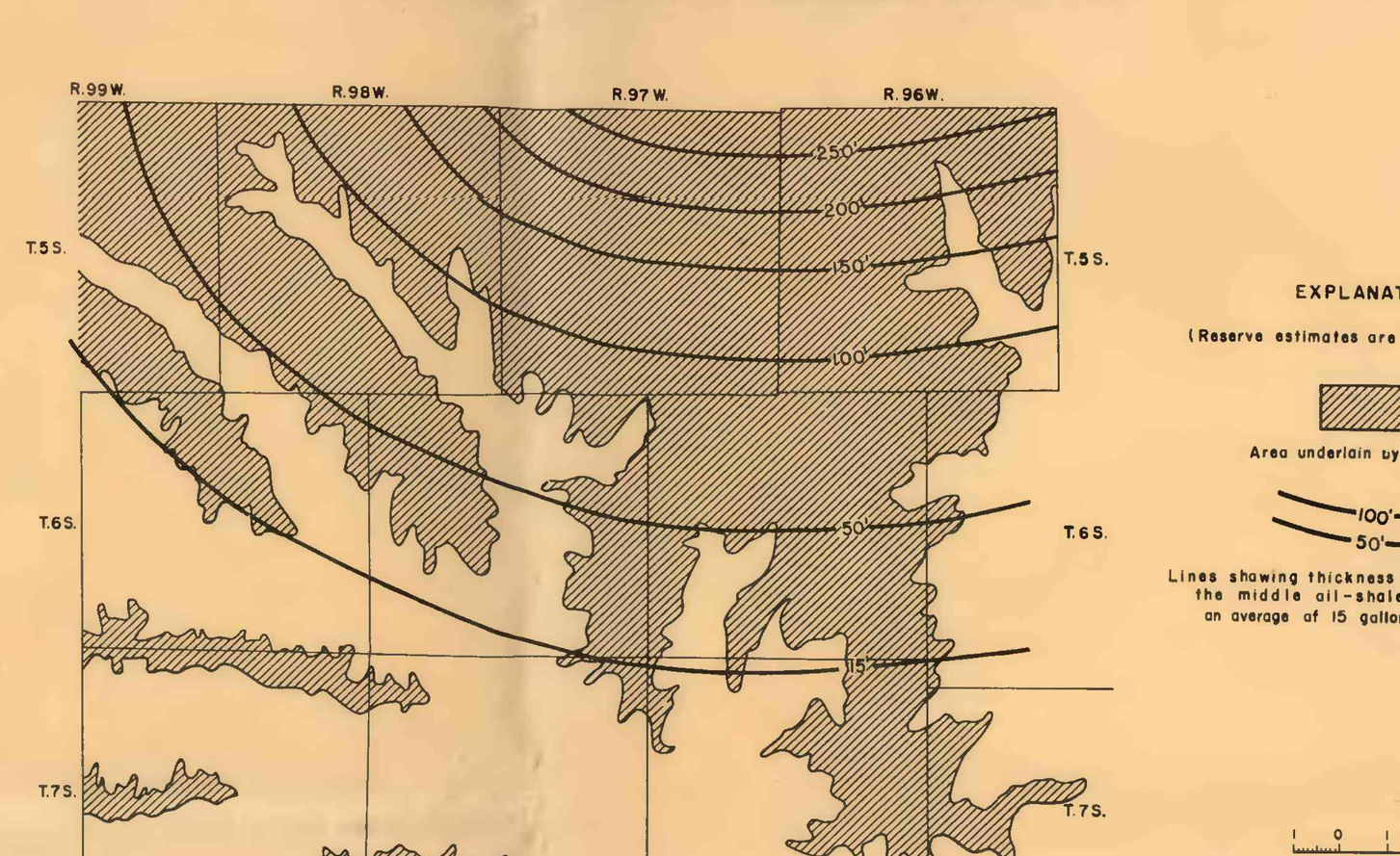


FIGURE 9. MAP SHOWING DISTRIBUTION AND THICKNESS OF PART OF THE MIDDLE OIL SHALE ZONE THAT YIELDS AN AVERAGE OF 15 GALLONS OF OIL PER TON

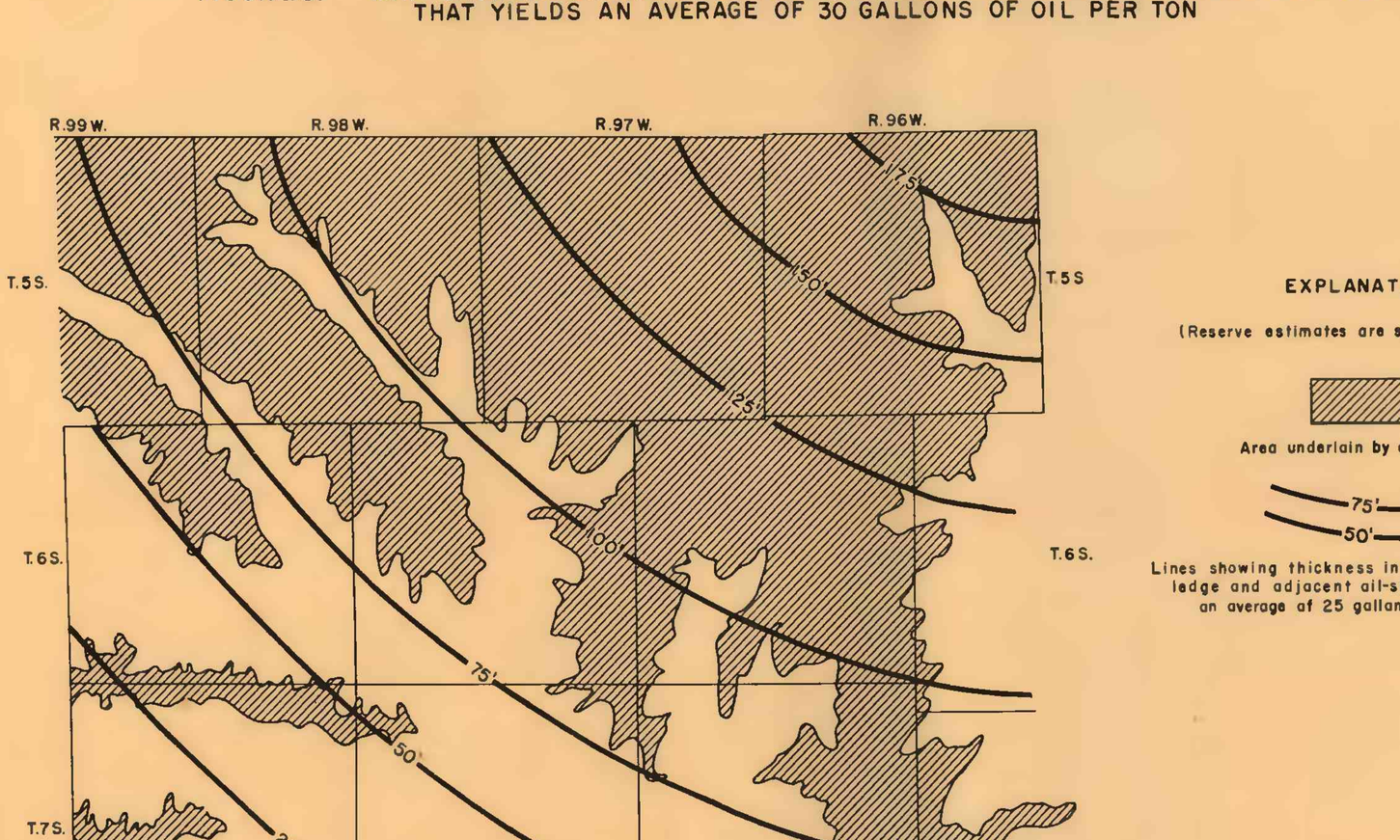


FIGURE 7. MAP SHOWING DISTRIBUTION AND THICKNESS OF THE MAHOGANY LEDGE AND ADJACENT BEDS THAT YIELD AN AVERAGE OF 25 GALLONS OF OIL PER TON

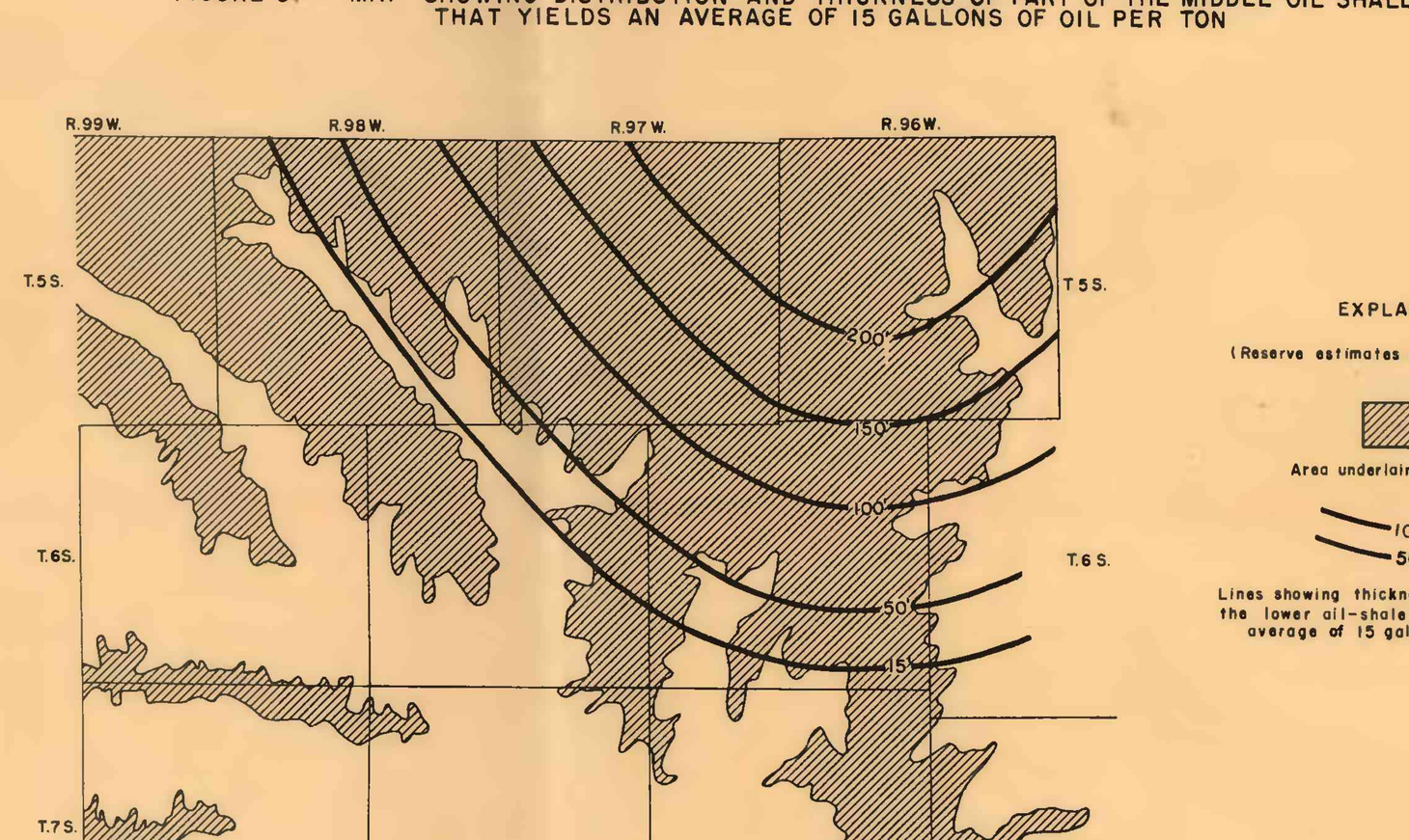


FIGURE 10. MAP SHOWING DISTRIBUTION AND THICKNESS OF PART OF THE LOWER OIL-SHALE ZONE THAT YIELDS AN AVERAGE OF 15 GALLONS OF OIL PER TON

TABLE 1. GENERALIZED DESCRIPTION OF THE ROCKS EXPOSED IN THE DEBEQUE OIL-SHALE AREA

System	Series	Formation	Member, thickness of unit, and character of rock	Mt. Callahan and vicinity	Western part of area
Tertiary			Igneous flow 50± feet		
Tertiary	Eocene	Green River formation	Evacuation Creek member: 650± feet. Gray and brown sandstone with interbedded gray marlstone and a few beds of oil shale and siltstone. Member weathers to rounded slopes.		
Tertiary	Eocene	Green River formation	Parachute Creek member: 580-1,200 feet. Black, brown, and gray marlstone including principal oil-shale zones. Few thin key beds of altered tuff, analcite, and chert. Tongues of sandstone and siltstone near base. Member weathers to light-gray and light-brown cliffs.		
Tertiary	Eocene	Green River formation	Garden Gulch member: 480-640 feet. Gray marlstone with some gray and brown shale and a few thin oil shales. Few algae beds. Weathers to smooth steep slopes.	Lower sandy member: 1,100± feet. Brown and gray sandstone and gray shale; a little gray marlstone near top. Member interfingers with Douglas Creek, Garden Gulch, and lower part of Parachute Creek members. Weathers to slopes and low cliffs.	Lower shaly member: 1,000-1,180 feet. Gray marlstone with few beds of gray and brown siltstone and limestone. Several thin oolite and algae beds. Member interfingers with Douglas Creek, Garden Gulch, and lower part of Parachute Creek members. Weathers to slopes and low cliffs.
Tertiary	Eocene	Green River formation	Douglas Creek member: 410-470 feet. Brown sandstone and gray shale, and a few beds of oolites and algae beds. Weathers to buff slopes and low cliffs.		
Tertiary	Eocene	Wasatch formation	1,100+ feet. Red, drab, gray, and maroon shale, and irregularly distributed lenticular sandstones. Weathers to varicolored slopes with discontinuous sandstone ledges.		

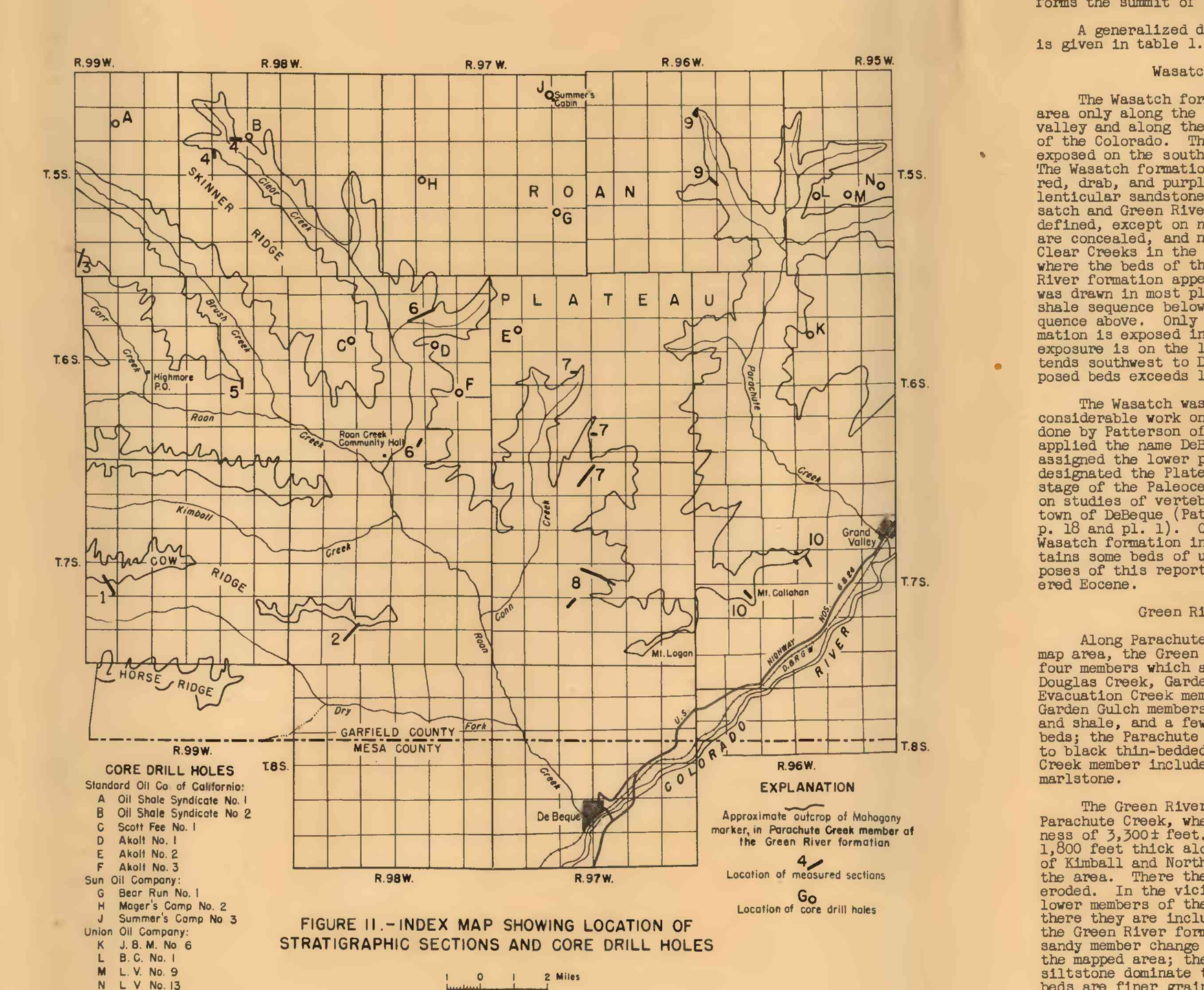


FIGURE 11.—INDEX MAP SHOWING LOCATION OF STRATIGRAPHIC SECTIONS AND CORE DRILL HOLES

TABLE 2. RESERVES OF THE RICHEST PARTS OF THE UPPER OIL-SHALE ZONE THAT YIELD 45, 30, AND 25 GALLONS OF OIL PER TON IN THE DEBEQUE AREA, GARFIELD COUNTY, COLORADO
(Estimates are total tonnage and total potential yield of oil shale in place. Recoverable reserves are less, owing to losses in mining.)

		Township and range	Acreage	Average thickness (feet)	Average tonnage per acre - thousands of tons (2000 lb.)	Average oil yield per acre - thousands of barrels	Tonnage per township (millions of tons)	Oil yield per township (Millions of barrels)
Unit 1	Part of the Mahogany ledge that yields an average of 45 gallons of oil per ton in continuous section 5 feet or more thick. (Distribution and thickness of zone shown in figure 5.)	T. 5 S., R. 96 W.	19,194	22	59	63	1,132	1,209
		T. 5 S., R. 97 W.	23,302	15	40	43	932	1,002
		T. 5 S., R. 98 W.	18,023	9	24	26	433	469
		T. 5 S., R. 99 W.	3,610	6	16	17	58	61
		T. 6 S., R. 96 W.	1,843	19	51	55	94	101
		T. 6 S., R. 97 W.	18,176	14	37	40	672	727
		T. 6 S., R. 98 W.	8,826	9	24	26	212	229
		T. 6 S., R. 99 W.	1,240	6	16	17	20	21
		T. 7 S., R. 96 W.	1,882	10	26	28	49	53
		T. 7 S., R. 97 W.	6,707	10	26	28	174	188
		T. 7 S., R. 98 W.	691	8	21	22	14	15
	TOTALS		103,494				3,790	4,075
Unit 2	Part of Mahogany ledge that yields an average of 30 gallons of oil per ton in continuous section 15 feet or more thick. Includes unit 1. (Distribution and thickness of zone shown in figure 6.)	T. 5 S., R. 96 W.	19,194	102	303	216	5,815	4,146
		T. 5 S., R. 97 W.	23,302	80	235	168	5,476	3,915
		T. 5 S., R. 98 W.	18,023	58	171	122	3,082	2,199
		T. 5 S., R. 99 W.	9,824	37	109	78	1,071	766
		T. 6 S., R. 96 W.	1,843	87	255	182	470	335
		T. 6 S., R. 97 W.	18,176	72	215	154	3,908	2,799
		T. 6 S., R. 98 W.	8,826	56	165	118	1,456	1,041
		T. 6 S., R. 99 W.	5,300	30	88	63	466	334
		T. 7 S., R. 96 W.	1,882	55	162	115	305	216
		T. 7 S., R. 97 W.	6,797	57	168	120	1,128	809
		T. 7 S., R. 98 W.	1,585	34	100	71	158	113
		T. 7 S., R. 99 W.	2,400	16	47	34	113	81
	TOTALS		117,062				23,448	16,754
Unit 3	Mahogany ledge and adjacent beds that yield an average of 25 gallons of oil per ton in continuous section 15 or more thick. Includes unit 2. (Distribution and thickness of zone shown in figure 7.)	T. 5 S., R. 96 W.	19,194	160	492	293	9,443	5,623
		T. 5 S., R. 97 W.	23,302	128	394	235	9,181	5,476
		T. 5 S., R. 98 W.	18,023	100	307	183	5,533	3,298
		T. 5 S., R. 99 W.	9,824	72	221	132	2,171	1,297
		T. 6 S., R. 96 W.	1,843	129	397	236	732	435
		T. 6 S., R. 97 W.	18,176	114	351	209	6,380	3,799
		T. 6 S., R. 98 W.	8,826	94	289	172	2,551	1,518
		T. 6 S., R. 99 W.	5,369	58	178	106	956	569
		T. 7 S., R. 96 W.	1,882	82	252	150	474	282
		T. 7 S., R. 97 W.	6,707	83	255	152	1,710	1,019
		T. 7 S., R. 98 W.	1,585	59	181	108	287	171
		T. 7 S., R. 99 W.	4,557	26	80	48	365	219
	TOTALS		119,288				39,788	23,706

TABLE 3. OIL-SHALE RESERVES YIELDING AN AVERAGE OF 15 GALLONS OF OIL PER TON, IN THE DEBEQUE AREA, GARFIELD COUNTY, COLORADO
(Includes stratigraphic intervals 15 feet or more thick; estimates show total tonnage and total potential yield of oil shale in place. Recoverable reserves are less, owing to losses in mining.)

	Township and range	Acreage	Average thickness (feet)	Average tonnage per acre - thousands of tons	Average oil yield per acre - Thousands of barrels	Tonnage per township - Millions of tons	Oil yield per township - millions of barrels
UPPER OIL-SHALE ZONE including the Mahogany ledge (Distribution and thickness shown in figure 8)	T. 5 S., R. 96 W.	18,259	650	2,141	765	39,093	13,968
	T. 5 S., R. 97 W.	23,270	579	1,907	681	44,375	15,847
	T. 5 S., R. 98 W.	16,761	473	1,558	556	26,114	9,319
	T. 5 S., R. 99 W.	9,383	323	1,064	380	9,984	3,566
	T. 6 S., R. 96 W.	1,344	575	1,894	676	2,546	908
	T. 6 S., R. 97 W.	17,273	545	1,795	641	31,005	11,074
	T. 6 S., R. 98 W.	7,423	464	1,529	546	11,349	4,053
	T. 6 S., R. 99 W.	4,294	277	913	326	3,920	1,400
	T. 7 S., R. 96 W.	973	358	1,179	421	1,147	410
	T. 7 S., R. 97 W.	5,350	390	1,285	459	6,875	2,456
	T. 7 S., R. 98 W.	692	288	949	339	657	235
	T. 7 S., R. 99 W.	4,109	97	320	114	1,315	468
SUB-TOTALS		109,131				178,380	63,704
MIDDLE OIL-SHALE ZONE (Distribution and thickness shown in figure 9)	T. 5 S., R. 96 W.	19,655	176	580	207	11,399	4,069
	T. 5 S., R. 97 W.	23,315	159	524	187	12,217	4,360
	T. 5 S., R. 98 W.	18,690	97	320	114	5,981	2,130
	T. 5 S., R. 99 W.	10,035	43	142	51	1,425	512
	T. 6 S., R. 96 W.	2,086	67	221	79	461	165
	T. 6 S., R. 97 W.	18,611	59	194	69	3,611	1,284
	T. 6 S., R. 98 W.	9,510	48	158	56	1,503	533
	T. 6 S., R. 99 W.	4,166	30	99	35	412	146
	T. 7 S., R. 97 W.	333	15	49	18	16	6
SUB-TOTALS		106,401				37,025	13,205
LOWER OIL-SHALE ZONE (Distribution and thickness shown in figure 10)	T. 5 S., R. 96 W.	22,413	203	669	238	14,994	5,334
	T. 5 S., R. 97 W.	23,367	150	494	176	11,543	4,113
	T. 5 S., R. 98 W.	10,170	61	201	72	2,044	732
	T. 6 S., R. 96 W.	2,451	102	336	120	824	294
	T. 6 S., R. 97 W.	17,606	80	264	94	4,648	1,655
	T. 6 S., R. 98 W.	3,578	51	138	49	494	175
SUB-TOTALS		79,585				34,547	12,303
TOTAL RESERVES ALL ZONES						249,952	89,212

INTRODUCTION

The DeBeque oil-shale area includes about 375 square miles of rugged land, chiefly in Garfield County, Colorado, north, northwest, and northeast from the town of DeBeque. The southernmost tip of the area lies in Mesa County. In the area many beds of oil shale, distributed through a sequence of marlstone that ranges from 550 to 1,225 feet in thickness in the Green River formation, are prospectively valuable as a source of liquid fuel.

Earliest prospecting of oil shale in Colorado was conducted in the area of Roan Creek and its tributaries about 1910. Prospecting was considerably more active during and after World War I, and by the early 1920's several experimental oil-shale processing plants had been constructed. With the development of large petroleum reserves in other parts of the United States during the late 1920's, interest in oil shale lagged until oil shortages developed during World War II. During the period from 1944 to 1949 several organizations sampled the oil shales of the DeBeque area and experimented in processing them. Phillips Petroleum Co., Standard Oil Co. of California, Union Oil Co., and Sun Oil Co. conducted surface or core-drill sampling and to varying degrees experimented in processing the oil shale. The U. S. Bureau of Mines conducted more extensive sampling and experimental mining and processing in the adjacent area to the east, which includes Naval Oil Shale Reserves 1 and 3.

The area north of the Colorado River, between Rifle and DeBeque, included partly in this report and partly in an earlier Geological Survey report on the Naval Oil Shale Reserves (Duncan and Denson, 1949), is perhaps most favorably situated for future development of an oil-shale industry in Colorado. The richest exposures of shale are found here and steep slopes below the oil shale cliffs allow for easy disposal of spent shale from retorting. Water of the Colorado River is close at hand but appropriation for other use may seriously interfere with its availability. U. S. Highways 6 and 24 and the main line of the Denver and Rio Grande Western Railroad facilitate the transportation of supplies to the area and afford access to markets. The oil shale near DeBeque constitutes only a small part of extensive deposits in western Colorado, eastern Utah, and southern Wyoming, which have been described in earlier Geological Survey reports (Winchester, 1923; Bradley, 1931)

The Green River formation forms an extensive plateau in northwestern Colorado, including the DeBeque oil-shale area, where its altitude is about 8,500 feet. The plateau is bordered by precipitous cliffs, known as the Roan Cliffs, formed by a thick sequence of marlstone and oil shale, below which steep, barren, talus-strewn slopes descend 2,500 to 3,500 feet to the valleys of the Colorado River and its tributaries. The north-facing slopes are relatively gentle and are covered with trees and brush. The southern margin of the plateau in the DeBeque oil-shale area is a few miles north of the Colorado River and is intricately and deeply incised by steep-walled canyons cut by tributaries of the Colorado. Many trails leading from the valley to the plateau afford comparatively easy access by foot or horseback to the more remote parts of the DeBeque area; automobile roads traverse the valleys, but the only automobile road on the plateau is along the north margin of the area.

Ten detailed stratigraphic sections spaced at intervals of 4 to 7 miles along the escarpment of the Green River formation were measured in the DeBeque area. The sections were measured with a hand level and 6-foot steel tape. All oil-shale beds were chipped clean with a pick, and small blocks of the beds were broken loose from the outcrop; such blocks were examined critically and an estimate of the oil content of the rock was made. Estimates of oil content were based on the color, luster, texture, specific gravity, and weathering features of the rock, and on comparisons of the field estimates with assays of selected samples. The measurement of these 10 stratigraphic sections demonstrated the persistence of many key beds that are present also throughout the Naval Oil Shale Reserves Nos. 1 and 3 (Duncan and Denson, 1949). The cores from nine core drill holes drilled by private operators in the DeBeque area, and the cores from two holes drilled by a private operator and from one hole drilled by the Federal Bureau of Mines, outside the area but within a few miles of its east boundary, were logged in detail. Many of the key beds recognized in the outcrops were identified in the cores. The 21 stratigraphic sections and the cores from 18 core-drill holes in the DeBeque oil-shale area and the adjacent Naval Oil Shale Reserves 1 and 3 show that many of the rich oil-shale beds persist through most of these two mapped areas.

Subsequent to the measurement of the stratigraphic sections the positions of the boundaries of the stratigraphic members and formations were mapped, using as a base the Geological Survey's topographic maps of the Parachute Creek, Grand Valley, Roan Creek, and Highmore quadrangles. Altitudes of several key beds and of the geologic boundaries were determined largely with aneroid barometers, although some altitudes were determined by plane-table and telescopic alidade.

The field investigation was carried on by Fred R. Waldron, John R. Donnell, James C. Wright, and W. M. Zilbersher, assisted part-time by W. A. Jenkins, Jr., between July and October 1948; the field data were compiled and the report was prepared by Waldron, Donnell, and Wright between November 1948 and June 1949, and data on reserves were modified by Donnell in 1950 according to sample data made available after the report was completed. Norman M. Denson, who was with the field party 10 days in July 1948, identified the formation and member boundaries and key beds, and demonstrated for the members of the field party the field methods used in previous investigations. The project was under the general supervision of N. W. Bass.

The writers are indebted to engineers of the U. S. Bureau of Mines and representatives of the oil companies working in the area, who allowed analyses of their drill cores and measured sections to be used in the computation of oil yields. Camp facilities were made available to the writers by the Standard Oil Co. of California during the latter part of August and the first part of September.

STRATIGRAPHY

The sedimentary rocks exposed in the DeBeque oil-shale area have a total thickness of about 4,100 feet; they consist, in ascending order, of interbedded vari-colored shale, lenticular sandstone and thin-bedded limestone of the Wasatch formation, and thin-bedded marlstone, oil shale, shale, and some sandstone of the Green River formation; both formations are of Eocene age. A small area of basalt of late Tertiary age forms the summit of Mt. Callahan.

A generalized description of the rocks exposed is given in table 1.

Wasatch formation (Eocene)

The Wasatch formation crops out in the mapped area only along the lower slopes of the Colorado River valley and along the valleys of the main tributaries of the Colorado. The formation is particularly well exposed on the south-, east-, and west-facing slopes. The Wasatch formation consists of interbedded gray, red, drab, and purple shale, sandy shale, and some lenticular sandstone. The boundary between the Wasatch and Green River formations is rather sharply defined, except on north-facing slopes, where the beds are concealed, and near the confluence of Roan and Clear Creeks in the south half of T. 6 S., R. 98 W., where the beds of the Wasatch and overlying Green River formation appear to interfinger. The contact was drawn in most places at the contact of a red shale sequence below with a brown and gray shale sequence above. Only the upper part of the Wasatch formation is exposed in the DeBeque area; the maximum exposure is on the lower slopes of Mt. Logan and extends southwest to DeBeque, where the thickness of exposed beds exceeds 1,100 feet.

The Wasatch was not studied in detail; however, considerable work on the Wasatch in this area has been done by Patterson of the Field Museum of Chicago. He applied the name DeBeque formation to the Wasatch and assigned the lower part of his DeBeque which he designated the Plateau Valley beds, to the Tiffany stage of the Paleocene age. This assignment is based on studies of vertebrate fossils collected near the town of DeBeque (Patterson, 1939; Wood et al, 1941, p. 18 and pl. 1). On this basis the lower part of the Wasatch formation in this general area probably contains some beds of upper Paleocene age but for purposes of this report the Wasatch formation is considered Eocene.

Green River formation (Eocene)

Along Parachute Creek in the eastern part of the map area, the Green River formation is divided into four members which are, in ascending order, the Douglas Creek, Garden Gulch, Parachute Creek, and Evacuation Creek members. The Douglas Creek and Garden Gulch members consist of tan and gray sandstone and shale, and a few thin limestone and algae reef beds; the Parachute Creek member contains mostly gray to black thin-bedded marlstone; and the Evacuation Creek member includes siltstone, sandstone, and brown marlstone.

The Green River formation is best exposed along Parachute Creek, where it attains its maximum thickness of 3,300± feet. The formation is only about 1,800 feet thick along Carr Creek and the upper part of Kimball and North Dry Fork in the western part of the area. There the upper part of the formation is eroded. In the vicinity of Mt. Callahan the two lower members of the formation were not distinguished; there they are included in the lower sandy member of the Green River formation. The rocks of the lower sandy member change facies in the southwestern part of the mapped area; there shale, siltstone, and limy siltstone dominate the sequence, and the sandstone beds are finer grained and thinner bedded than elsewhere in the area. The sequence in the southwestern part of the area, accordingly, has been designated the lower shaly member.

The Garden Gulch member is interpreted to represent offshore deposits that accumulated north of an arc projected through Mt. Callahan and between Mt. Logan and DeBeque, and thence northwest, passing through the east part of Cow Ridge to Carr Creek, and thence up Carr Creek to the west boundary of the mapped area. South of this area rocks equivalent to the Garden Gulch member are coarser textured, contain more sandstone, and appear to have been deposited near shore. The oil shales of the Parachute Creek member, however, extend south of the arc that separates the near-shore deposits from the offshore deposits of the Garden Gulch.

Douglas Creek member. The Douglas Creek member of the Green River formation consists of gray, brown, and buff shale; lenses of fine-grained sandstone, silty sandstone and fine-grained limestone; and a few thin oolite and algae beds. The member contains only a few oil-shale beds, each of which is only a few inches thick. The thickness of the member ranges from 400 to 470 feet on Parachute Creek and is about 410 feet on the lower part of Clear Creek. The member forms buff slopes and low cliffs.

Garden Gulch member. The Garden Gulch member of the Green River formation overlies the Douglas Creek member; it consists of gray and buff marlstone, lesser amounts of shale and limestone, and a few thin beds of oil shale and, particularly in the lower part, beds containing algae, ostracods, and oolites. The thickness of the Garden Gulch member ranges from 640 feet in Bowdish Gulch, southwest of Parachute Creek, to 480 feet on the lower part of Clear Creek. In the vicinity of Mt. Callahan sandy and silty beds extend up into and interfinger with the marlstone beds, which elsewhere occupy the greater part of the member. Along the western margin of the mapped area sandy and silty beds and much shale interfinger with the marlstone beds. The member weathers to steep smooth slopes.

Lower sandy member. The lower sandy member of the Green River formation is exposed only on the north, east, and south slopes of Mt. Callahan. It is the stratigraphic equivalent of the combined Douglas Creek and Garden Gulch members and the lowermost part of the Parachute Creek member. The lower sandy member consists of brown- and gray-weathering sandstone and interbedded gray shale, and a few thin beds containing algae reefs, oolites, and ostracods. The upper part contains much gray marlstone, parts of which are silty. The thickness of the member is about 1,100 feet. It forms long steep slopes and low cliffs.

Lower shaly member. The lower shaly member of the Green River formation is exposed along North Dry Fork, Kimball Creek, and the upper part of Roan Creek in the westernmost part of the mapped area. It is approximately equivalent to the lower sandy member, and therefore is equivalent also to the combined Douglas Creek and Garden Gulch members and the lowermost part of the Parachute Creek member. The upper part of the lower shaly member consists mainly of gray marlstone that is barren of oil shale, and a few beds of gray and brown siltstone and limestone, some of which are dolomitic. The lower part of the member consists largely of gray shale. Beds of limestone, ranging in thickness from a few inches to 4 feet and containing algae reefs, oolites, and ostracods, are widely distributed through the member. The member ranges in thickness from about 1,000 to 1,180 feet. It forms slopes and low cliffs.

Parachute Creek member. The Parachute Creek member of the Green River formation overlies the Garden Gulch member; it ranges in thickness from 580 feet on the western margin of the mapped area to 1,200 feet in the central part of the area. Its outcrops form the Roan Cliffs, which are 500 to 1,000 feet high and cap the long steep slopes of the underlying members of the Green River formation. The Parachute Creek member consists of thin-bedded marlstone that contains varying amounts of organic matter and constitutes the principal oil-shale beds. The member contains the lower, middle, and upper oil-shale zones; and sequences of beds that contain relatively few beds of oil shale are present between the oil-shale zones (fig. 1). Interbedded with the marlstone beds are (1) partings and thin beds of altered tuff, (2) chert layers, (3) thin beds or partings composed of minute calcite and dolomite grains, (4) thin zones containing many gypsum and anhydrite crystal cavities, and (5) thin lenses of fine-grained sandstone; the sandstone beds are present chiefly in the westernmost part of the mapped area.

Lower oil-shale zone. The lower oil-shale zone ranges in thickness from 320 feet in the easternmost part of the area to 70 feet at the east end of Cow Ridge in the south-central part of T. 7 S., R. 98 W. The content of organic matter in the rocks diminishes rather abruptly west of the east end of Cow Ridge and essentially disappears between that place and the west margin of the mapped area; there, the interval occupied by the zone forms the uppermost part of the lower shaly member. The lower oil-shale zone consists largely of thin- to massive-bedded marlstone that weathers gray or bluish gray. The marlstone contains varying amounts of organic matter; it also contains many thin altered tuff or analcite partings and thin beds of limestone, algae reefs, and oolitic limestone. The strata in the zone range from beds that are nearly barren marlstone to beds capable of yielding more than 44 gallons of oil per ton. Most beds of the zone, however, yield less than 15 gallons per ton.

Middle oil-shale zone. The middle oil-shale zone ranges in thickness from 120 feet in the eastern part of the area to less than 10 feet on Cow Ridge at the west edge of the area. It is separated from the lower oil-shale zone by a sequence of marlstone beds containing relatively small amounts of organic matter, whose thickness ranges from 40 to 180 feet. The middle oil-shale zone is composed largely of thin-bedded to massive-bedded shale and marlstone, which weather gray, dark blue, and nearly black; the potential oil yield of the beds ranges from a few gallons to 45 gallons per ton. In the northeast part of the area, part of the middle oil-shale zone averages more than 15 gallons per ton in oil yield, but elsewhere the average oil yield of units more than 15 feet thick is less than 15 gallons per ton. The zone contains many thin altered tuff and analcite partings, and in the area between Conn Creek and Parachute Creek it contains several algae reefs and oolitic beds. Beds of limestone are rare or absent in the middle oil-shale zone in most places, but near Old Highmore Post Office, in T. 6 S., R. 99 W., where a stratigraphic section (column 5, figs. 1 and 4) was measured, many beds of limestone that are essentially barren of organic matter are present.

A sequence of marlstone beds, 14 feet to about 40 feet thick that is relatively barren of oil shale overlies the middle oil-shale zone. At most places this sequence of beds weathers into a groove in the cliffs or to a gentle slope between cliffs of the more resistant oil shale. The beds that form the groove are largely marlstone that contains a few thin partings of analcite. In the western part of Cow Ridge, in the southwestern part of the area, however, the groove is absent because there the resistant beds of limy fine-grained sandstone occupy the stratigraphic position of the groove.

Upper oil-shale zone. The upper oil-shale zone ranges in thickness from 590 feet in East Fork of Conn Creek to 440 feet at the upper end of Clear Creek. The zone consists almost entirely of thin- to massive-bedded marlstone (oil shale), which weathers light gray to nearly black. Many thin altered tuff or analcite partings and a few analcitized tuff beds ranging from 0.5 foot to about 3 feet in thickness are present throughout the zone. These analcitized tuff beds serve as key markers. Some of the marlstone beds in the upper few feet of the zone are silty.

The upper oil-shale zone contains the richest oil-shale beds of the Parachute Creek member. Some beds have a potential oil yield of as much as 60 gallons per ton. The richest of these beds ranges from 5.6 to 10.0 feet in thickness and is known locally as the "Mahogany bed." The potential oil yield of the "Mahogany bed" is less in the westernmost part of the area than elsewhere. The "Mahogany bed" lies from 5.2 to 14.0 feet below the Mahogany marker, a thin persistent bed composed chiefly of analcite, whose stratigraphic position is shown on figures 1 and 4; the interval between the two beds decreases westward across the area. A sequence of beds 10 to 130 feet thick in the lower part of the upper oil shale zone is referred to as the Mahogany ledge (Bradley, 1931, p. 23); it includes the "Mahogany bed" of local usage and numerous other rich beds that are similar to old mahogany in their reddish-brown color and their texture. In the mapped area the Mahogany ledge constitutes the thickest sequence of beds of oil shale whose average oil yield exceeds 25 gallons per ton. In general, the oil-shale beds are richest and thickest in the northeastern part of the area. The richest oil-shale beds weather grayish white or blue gray and form resistant ledges throughout the area.

Cavities ranging from less than a foot to about 5 feet in diameter are present through much of the Parachute Creek member above the "Mahogany bed." These cavities were formed by the leaching of nahcolite, a sodium bicarbonate mineral, which was precipitated out of lake waters during the deposition of the Green River sediments (Bradley, 1930a, pp. 5-6; 1931, pp. 32-35).

Key beds of the Parachute Creek member. Several key beds present in the Parachute Creek member persist throughout the area, and were identified in the 10 stratigraphic sections measured (fig. 4). Perhaps the most widely used key bed is the analcitized tuff bed known as the Mahogany marker; it lies from 40 to 114 feet above the base of the upper oil-shale zone and from 5 to 14 feet above the "Mahogany bed." The Mahogany marker is a bed about 0.5 foot thick, composed mainly of analcite crystals 0.1 to 2.0 mm in diameter. The surface of the bed is commonly gray, but locally it is brown, owing to a coating of asphalt on the analcite crystals; at several places an iron stain has imparted a reddish hue to the bed. The most conspicuous key bed in core drill holes is an analcitized tuff bed that lies 118 to 200 feet above the base of the upper oil-shale zone. This bed is characterized by wavy interbedded lenses of marlstone of varying thickness ranging from a foot or less to 3 feet. A thin analcite parting was observed throughout the area in the upper part of the Parachute Creek member. It lies 200 to 260 feet above the Mahogany marker, is associated with the uppermost of three thin but prominent ledge-forming rich oil-shale beds, and in most places lies 20 to 38 feet below the lowest mappable gypsum-anhydrite crystal cavity zone. This key bed is particularly useful in identifying the upper boundary of the rich oil-shale beds.

Evacuation Creek member. The Evacuation Creek member overlies the Parachute Creek member, and in most places is exposed in rounded slopes along the margins of the Roan Plateau. The contact between the Evacuation Creek member and the underlying Parachute Creek member was drawn at the base of the lowermost massively bedded siltstone or sandstone. The Evacuation Creek member, as mapped in the DeBeque area, attains a thickness of as much as 650 feet in the area northwest of Mt. Callahan, although there the upper part of the sequence designated as Evacuation Creek possibly includes some beds belonging to the Bridger formation. The lower 200 feet of the Evacuation Creek member consists largely of lenticular and channeled gray siltstone and sandstone, yellow, and brown fine- to medium-grained sandstone containing some plant remains. Marlstone containing low-grade oil shale is present locally in the lower part of the Evacuation Creek member. In general, the Evacuation Creek member weathers to yellow and brown rounded slopes.

Igneous rocks

The summit of Mt. Callahan is underlain by a basalt flow about 50 feet thick. Ogden Tweto examined microscopically two thin sections of the rock collected at Mt. Callahan and reported orally that the groundmass consists of plagioclase (labradorite), some magnetite and augite, and a small amount of olivine and calcite or dolomite. The phenocrysts are principally augite and olivine, but there are a few aggregates of calcite or dolomite grains pseudomorphic after plagioclase, and a few large crystals of apatite.

Andesite and basalt flows of late Tertiary and Quaternary (?) age are present on Battlement Mesa (Burbank et al., 1935), 12 miles southeast of Mt. Callahan. The altitude of Mt. Callahan is 8,607 feet and the altitude of the highest point on Battlement Mesa is 9,282 feet. Accordingly, it appears likely that the basalt on Mt. Callahan is an outlier of one of the flows on Battlement Mesa. As the basalt on Mt. Callahan apparently was deposited prior to cutting of the Colorado River canyon, it is probably of late Tertiary age.

STRUCTURE

Most of the DeBeque oil-shale area is on the southwest flank of the Piceance Creek Basin, which is a broad regional structural feature 100 miles or more long and 40 miles or more wide, trending slightly east of south across the southwestern part of northwestern Colorado (Bradley, 1931, pl. 1). The axis of a structural basin trends southeast across the DeBeque oil-shale area, passing about 3 miles southwest of its northeast corner (fig. 2). This axis may be that of the Piceance Creek Basin, but mapping north of the DeBeque area will be required before the relation of the two features can be established. The dip of beds of the Green River formation on the part of the northeast flank of the basin lying in the northeastern part of the DeBeque area is only 50 feet to the mile (Duncan and Denson, 1949). Farther east the dip increases on the southwest flank of the Grand Hogback monocline, which forms the east boundary of the Piceance Creek Basin.

The average rate of dip of the Green River beds on the southwest flank of the regional structural basin in the DeBeque oil-shale area is about 40 feet to the mile, but this regional dip is interrupted by two well-defined but low-dipping structural features--the Crystal Creek anticlinal nose and the Clear Creek basin, both of whose axes trend southeast. The rate of dip on the northwest flank of the Crystal Creek anticlinal nose is about 100 feet to the mile and the rate of dip on the steepest part of its southwest flank is 200 feet. The average dip on the southwest flank of the Clear Creek basin is only slightly greater than the regional dip of 50 feet to the mile. It is noteworthy that Clear Creek follows closely the axis of the Clear Creek basin.

The structure contours shown on figure 2 were drawn on the Mahogany marker. Structural data collected in the field on beds in the Douglas Creek, Garden Gulch, and Evacuation Creek members of the Green River formation and on beds in the Wasatch formation indicate that the attitude of all beds in these formations conforms to the attitude shown for the Mahogany marker.

CHARACTER OF THE OIL SHALE AND ASSOCIATED MARLSTONES

The character of the marlstones, including the oil shale of the Parachute Creek member of the Green River formation, has been previously described in detail (Bradley, 1931, pp. 22-32); most of the essential features, however, are repeated below. The oil shale is marlstone that has an appreciable content of organic matter; it is a very fine grained carbonate rock, finely laminated to massively bedded; it weathers to gray, light brown, or to a blue gray or white, the color apparently being controlled by the amount of organic matter present. In general, the marlstone rich in organic matter weathers blue gray or bluish white, and a rock containing small amounts of organic matter weathers gray or light brown. Freshly broken surfaces of oil shale are gray to brown or black. Most of the rich oil-shale beds have a waxy or satiny luster on fresh fracture and the lean beds have a dull luster.

Owing to the large amount of organic matter present in the oil-shale beds, they are more resistant to weathering than the beds of shale and marlstone that are interstratified with them. The effect of differential weathering is particularly conspicuous on steep slopes and cliffs, where the rich oil-shale beds form prominent overhanging ledges and the lean marlstone beds form grooves or recesses. The rich oil-shale beds are tough and break with an irregular fracture; weathering causes them to split along bedding planes. Moreover, the bedding planes are sharply defined and persistent. In the mining operations being conducted by the U. S. Bureau of Mines 10 miles east of the DeBeque oil-shale area, the rich oil-shale beds are separated readily from the overlying lean beds. The lean beds there form a smooth roof, which shows remarkable strength in underground workings 60 feet or more wide.

Most of the marlstone beds containing much organic matter (oil shales) are thinly laminated, the laminae being alternately rich and lean in organic matter. The occurrence of the laminae is rhythmic or cyclic in many beds; such laminae have been interpreted by Bradley (1930b, pp. 95-96; 1931, p. 26) as varves. Some marlstone beds contain subangular to rounded fragments of reworked oil shale distributed irregularly throughout the beds. These beds or sequence of beds, which in most places range from 1 to 6 feet in thickness, locally contain tight folds and contorted laminae; such beds are commonly rich in organic matter.

The specific gravity of marlstone of the Green River formation ranges from about 1.67 for rich oil shale, which is capable of yielding 75 gallons of oil per ton, to about 2.5 for lean oil shale, which is capable of yielding 10.5 gallons of oil per ton (U. S. Bureau of Mines, 1949, p. 44). The specific gravity of the rock is, in general, inversely proportional to the content of organic matter.

COMPOSITION OF THE MARLSTONE AND OIL SHALE

Investigations by Bradley (1931, pp. 29-32) have shown that (1) the major components of the marlstone are inorganic, and in some beds they may constitute 100 percent of the total; (2) the chief minerals are dolomite and calcite and they may comprise from 50 to 75 percent of the rock; (3) the clay minerals, which are assigned to the beidellite group, form about 20 percent of the inorganic constituents; analcite comprises 1 to 16 percent of the inorganic matter of some beds; (4) small amounts of detrital minerals such as quartz, mica, feldspar, and apatite are normally present; (5) the syngenetic minerals, in small amounts, consist of pyrite, opal, chert, and apophyllite, in addition to the more abundant analcite; the presence of pyrite is noteworthy because the pyrite yields sulfur to the shale oil (Gavin, 1924, p. 32) and sulfur must be removed in refining; (6) the organic matter in the rock ranges from a trace to 50 percent; it produces a black or brown surface on the unweathered rock, but in thin sections of the rock it is itself yellow, reddish brown, and black; most of the organic matter when viewed through the microscope appears to be structureless; thin sections of the material, however, reveal the presence of some simple aquatic plants and animals, a variety of pollens and spores, and remains of insects and fish.

RESERVES

Oil shales in the DeBeque area are richest and thickest northeast from Brush and Roan Creeks. The organic matter in all three oil-shale zones of the Parachute Creek member becomes gradually less southwest of Brush and Roan Creeks, where the oil shales interfinger with barren sandstone and grade into barren marlstone and shale.

During 1949 there was no large-scale commercial extraction of oil from the deposits of the area, so that estimates of oil available under probable commercial conditions can only be approximated. Research groups investigating mining and extraction methods are considering large-scale underground mining from the Mahogany ledge, a stratigraphic zone that ranges from 15 to 130 feet in thickness and that yields an average of 25 to 30 gallons of oil per ton.

Reserve estimates that accompany this report were prepared for the richest part of the Mahogany ledge, which yields an average of 45 gallons of oil per ton; for the part of the Mahogany ledge yielding an average of 30 gallons of oil per ton; and for the Mahogany ledge and adjacent beds yielding an average of 25 gallons of oil per ton. Oil shale yielding 15 gallons of oil per ton has been considered the lowest-grade rock in the area that may be of possible future economic value as a source of synthetic liquid fuel. Estimates of these lower-grade reserves for thicker parts of the upper, middle, and lower oil-shale zones were also prepared. These estimates show a wide range in potential oil reserves with the different cutoff values of average oil yield.

Estimates of the potential oil yields of the deposits are based generally on measured sampled sections and careful measurement of areas underlain by oil shale. The oil yields of most samples were determined by the modified Fischer Assay (Stanfield and Frost, 1949) and similar sample retorts that determine the amount of oil extractable from a sample by heating in a closed retort system but do not indicate the total amount of organic matter. Some experimental retorts of other design are reported to yield less, others to yield more oil per sample than the Fischer retort. Recent studies (U. S. Bureau of Mines, 1949, p. 45) have shown that when samples of oil shale, which had been crushed to fragments whose diameters were 0.5 inch or less, were naturally weathered the oil yield was reduced about 4.2 percent after weathering for 24 months. Analyses of fresh samples from core holes and of samples from nearby surface sections show an even greater difference in the oil yield. The field estimates of oil yield from surface sections were based mainly on comparison of physical properties of selected samples for which analyses had been made. Although these field estimates approximate roughly the yields obtained by analyses of surface samples, they are generally lower. In general the reserve estimates are thought to be low for parts of the area where field estimates alone were available to determine the quality of the oil shale.

The reserve estimates of the upper oil-shale zone and particularly the Mahogany ledge are considered reasonably accurate, particularly for the northern part of the map area, where a large amount of analyzed sample data and stratigraphic data show a uniform increase in quality and gradual increase in thickness of the rich oil shales northeastward. These reserves are classifiable mostly as "measured reserves" but include some "indicated reserves." For the area south of Brush and Roan Creeks the reserve estimates of the upper oil-shale zone are considered less accurate, however, as they are based mainly on field estimates of oil yield, from only a few incompletely analyzed sample sections. Likewise, reserve estimates for the middle and lower oil-shale zones are considered less accurate for the map area as a whole, because they are based mostly on field estimates of oil yield and on only a few analyzed sampled sections. These reserves are classifiable as mostly "indicated" but locally include small amounts of "measured" reserves.

The estimates of reserves represent an approximation of the total tonnage of rock in the ground and the total amount of oil that could be extracted from that amount of rock with present methods of processing. Recoverable oil from deposits of the area, however, would be much less, owing to losses in mining, as only 50 to 65 percent of the oil shale would be recovered with present underground mining methods.

The richest part of the Mahogany ledge, which yields 45 gallons of oil per ton in a zone 5 feet or more thick, is estimated to have a potential yield totaling about 4 billion barrels of oil. Details of distribution, thickness, tonnage, and oil yield of the unit are shown in table 2 (unit 1) and figure 5.

The part of the Mahogany ledge that yields an average of 30 gallons of oil per ton in continuous section 15 feet or more thick is estimated to have a total potential yield of about 16.7 billion barrels of oil, as shown in table 2 (unit 2) and figure 6.

The Mahogany ledge and adjacent beds that yield an average of 25 gallons of oil per ton in continuous section 15 feet or more thick are estimated to have a total potential yield of approximately 23.7 billion barrels of oil as shown in table 2 (unit 3) and figure 7.

Parts of the lower, middle and upper oil-shale zones that yield 15 gallons of oil per ton in sections 15 feet or more thick have a total potential yield of about 89 billion barrels of oil in the DeBeque area. Details of distribution, thickness, tonnage of rock, and oil yield of these zones are shown in table 3, figure 8 (upper oil-shale zone), figure 9 (middle oil-shale zone), and figure 10 (lower oil-shale zone).

REFERENCES

Bradley, W. H., 1930a, The occurrence and origin of analcite and meerschaum beds in the Green River formation of Utah, Colorado, and Wyoming: U. S. Geol. Survey Prof. Paper 158, pp. 1-7.

Bradley, W. H., 1930b, The varves and climate of the Green River epoch: U. S. Geol. Survey Prof. Paper 158, pp. 87-110.

Bradley, W. H., 1931, Origin and microfossils of the oil shale of the Green River formation of Colorado and Utah: U. S. Geol. Survey Prof. Paper 168.

Burbank, W. S., et al., 1935, Geologic map of Colorado, U. S. Geol. Survey

Duncan, D. C., and Denson, N. M., 1949, Geology of Naval Oil Shale Reserves 1 and 3, Garfield County, Colorado: U. S. Geol. Survey Oil and Gas Inv. Prel. Map. 94.

Gavin, Martin J., 1924, Oil shale--an historical, technical, and economic study: U. S. Bur. Mines Bull. 210.

Patterson, B., 1939, New Pantodonta and Dinocerata from the upper Paleocene of western Colorado: Field Mus. Nat. Hist., Geol. Ser., vol. 6, pp. 351-384.

Stanfield, K. E., and Frost, I. C., 1949, Method of assaying oil shale by a modified Fischer retort: U. S. Bur. Mines R. I. 4477.

U. S. Bureau of Mines, 1949, Synthetic liquid fuels, 1948 Annual Report of the Secretary of the Interior, Part II, Oil from oil shale: U. S. Bur. Mines R. I. 4457.

Winchester, D. E., 1923, Oil shale of the Rocky Mountain region: U. S. Geol. Survey Bull. 729.

Wood, H. E., et al., 1941, Nomenclature and correlation of the North American continental Tertiary: Geol. Soc. America Bull., vol. 52.

INTERIOR—GEOLOGICAL SURVEY, WASHINGTON, D. C.

GEOLOGY OF DEBEQUE OIL-SHALE AREA, GARFIELD AND MESA COUNTIES, COLORADO

By
Fred R. Waldron, John R. Donnell, and James C. Wright

1951

Drafting by Marjorie M. Hicks

OIL AND GAS INVESTIGATIONS
MAP OM 114 (IN 2 SHEETS) SHEET 2

For sale by U. S. Geological Survey, price $1.25 per set